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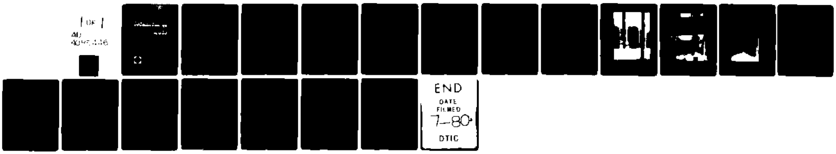

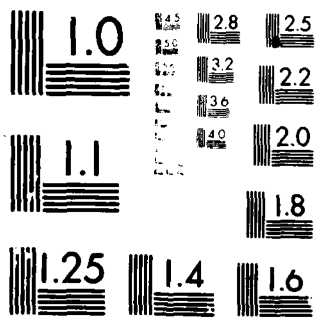

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An abbreviated research study on use of shrinkage-compensating expansive concrete in sandwich-type wall and roof panels containing insulation at mid-thickness is described. The use of expansive concrete is shown to be a technically viable concept for eliminating shrinkage cracking, thus preventing moisture penetration which can reduce insulation effectiveness, cause deterioration of the insulating material, and accelerate steel corrosion. Embeddable

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INTRODUCTION

Penetration of water into reinforced portland cement concrete structures through shrinkage cracks necessitates expensive installation of membranes and maintenance coatings. In addition, air infiltration through these cracks increases the heating/cooling energy load. In exterior walls and roofs, especially in areas where wind-driven rain is a problem, attempts to bridge working cracks with flexible and expandable coatings have met with only qualified success. Expansive cements were developed to (1) overcome the effects of shrinkage and (2) provide significant compressive prestressing for strength improvement (Ref 1). Detailed recommendations for use of shrinkage-compensating expansive cements were published in 1977 (Ref 2).

Commensurate with the demands for energy conservation, sandwich-type expansive concrete wall and roof panels containing insulation at mid-thickness should reduce life-cycle and energy costs of new structures by up to 30%, based on contractors' cost estimates. This saving results from use of concrete wall panels combining insulation and reinforcement. Two of the sandwich walls include "W" Panels made by CS&M Inc., Chino, Calif., and "Impac Panel" made by Covington Brothers Building Systems, Riverside, Calif. The objective of this study is to determine (1) the practicability of using expansive cement mortars to prevent shrinkage cracking and (2) the effective aged thermal resistance of the sandwiched urethane foam, originally in contact with wet mortar (plaster) on both sides.

Research directed toward development of sandwich-type walls and roofs began in FY 1976 at the Civil Engineering Laboratory, Port Hueneme, Calif., but demands for research funds for other studies resulted in drastically reduced support for the work in FY-TQ, -77, and -78. The study was terminated in FY-78.

In the first year of research (FY-76), the only expansive cement commercially available was Type K shrinkage-compensating cement. The one chosen for experimentation that year was Type K, ChemComp patented by Chemically Prestressed Concrete Corporation, Hacienda Heights, Calif.

Wall and roof panels of the type desired for the experiments were obtained from CS&M Incorporated, Chino, Calif., which makes and markets the panels under the trade name "W-Panel." These panels have been used in construction of houses, barns, and other structures for several years; their greatest use has been outside the continental United States. CS&M states that W-Panels have been used extensively on the island of Guam in U.S. Government housing and that houses made with these panels have successfully withstood severe typhoons. Authorities at Naval Station, Guam have verified use of these panels in housing but were unable to pinpoint locations. Use of W-Panels within the continental U.S. has been impeded by inertia in changing current building codes. The International Conference of Building Officials (ICBO) Uniform Code has approved the use of the panel under their research committee recommendation, Report No. 2440 (Ref 3).

Small sections of typical panels can be seen in Figure 1. The panel section on the left is set in a simulated footing. The sections shown contain 1 inch of polyurethane foam at mid-thickness; 2 by 2-inch no. 14 galvanized mesh forms the reinforcing on both sides of the foam. The two mats of fabric, one on each side of the foam, are tied together by single no. 14 wires welded to each mat and placed at 45 degrees from the plane of the mat to provide shear strength. About 1 inch of portland cement plaster or mortar is then applied to both sides of the panel to complete the construction. After the concrete has hardened, a finish coat of stucco (including color) may be applied.

Plastered or mortared panels will shrink when drying (i.e., when used in a typical wall or roof). If the shrinkage, which is a shortening in length due to loss of water, is restrained or resisted by reinforcement, tensile stresses develop in the material which can exceed its tensile strength, resulting in a crack. Steel reinforcing tends to hold cracks "closed," but moisture can penetrate as a vapor; heat and cold also find their way through. In an insulated wall or roof panel, water vapor can, and often does, condense in the insulation, thus reducing its insulation efficiency by increasing its thermal conductivity. The purpose of using shrinkage-compensating cement in the plaster (or mortar) is to provide enough induced compressive stresses in the hardened plaster to prevent shrinkage cracking, thus making the resultant construction more energy efficient.

EXPERIMENTAL PROGRAM

Descriptions of the test panels and conditions in the research program undertaken to provide crack-free, sandwich-type insulated, expansive concrete walls and roofs follow.

Cement: Type K, Shrinkage-Compensating

Cement content: 5.5 bags/cu yd

Sand/cement ratio: 3.5/1; 3.0/1

Panel size: (1) 2 by 4 feet; (2) 1 by 2 feet

Panel thickness: approximately 3 inches

Insulation thickness: 1 inch

Strain measurement: (1) mechanical strain gage
(2) embedded resistance strain gage

Number of panels: Twenty-one

INSTRUMENTATION

At the outset of the experimental program, it was planned to measure expansion strain and subsequent shrinkage with a mechanical strain gage on reference points cast into the wet concrete after construction of the panels. In addition, reference points were soldered to the mesh reinforcing at selected locations to measure steel movement. Later in the program, embeddable resistance strain gages were also used.

TEST RESULTS

The first experimental panels were 2 by 4 feet and were constructed out-of-doors (Figure 2). They were cast into simulated footings to enable them to stand upright without bracing. In Figure 2 the final layer of mortar had been applied to the panel on the left, while only the first lift of mortar had been applied to the one on the right. These panels were cured under wet burlap for 2 days and were then allowed to dry under ambient climatic conditions.

At first mechanical strain gage data seemed to be of reasonable magnitude, but after a few weeks very peculiar readings began to appear; in addition, some of the reference points loosened. The earlier readings had shown rather high shrinkage strains immediately following the curing period; at first, they seemed to be reasonable considering the rather thin concrete sections involved (approximately 1 inch). It is highly probable that screws used as the reference points were not securely bonded to the concrete (probably because they had to be pushed into the wet concrete after it had been brought to the proper level). The screws could not be pre-attached without tying them to the mesh, which would have defeated the purpose. It was eventually concluded that the mechanical strain gage data on these two panels were incorrect, and the information was discarded. Strains in the steel mesh, measured on reference points soldered to the steel, were also erratic.

Immediately following construction of the 2 by 4-foot panels, a series of 1 by 2-foot panels were constructed and instrumented for measurement with a mechanical strain gage. One of these panels can be seen in Figure 3. These panels were cured in fog for either 9 or 16 days prior to being placed in controlled temperature and humidity rooms (50% or 75% RH) for shrinkage determination. As with the larger panels, mechanical strain gage data seemed to be realistic for a while and then began to vary beyond reasonable limits.

By the time 20 panels had been constructed and it had been concluded that mechanical strain gage measurements were unreliable, financial support for the work was severely reduced. For FY-TQ, FY-77, and FY-78 measurements were continued on existing panels, but no additional experimental panels were constructed except for one additional 1 by 2-foot panel instrumented with embeddable resistance strain gages. The panel was cured for 16 days in fog and then placed in 50% RH. The embedded strain gages performed very well. Figure 4 shows shrinkage strains in 50% RH for this panel as well as average shrinkage strains for several of the panels in which the strain was measured with a mechanical strain gage. In terms of desired results (i.e., adequate expansion during the curing period to overcome subsequent shrinkage), the upper curve is much better than the lower curve. When the shrinkage curve drops below the horizontal zero strain line, it is in the tension or potential cracking zone.

Neither of the curves in Figure 4 shows sufficient expansion. In the case of the upper curve (measured with embedded resistance gages), the expansion should be about 200 microstrain (29%) higher to overcome the drying shrinkage expected in a dry climate (20% RH).

DISCUSSION

Optimum (and practical) curing procedures as well as optimum cement content are vital to achievement of adequate expansion. Adequate expansion to overcome (compensate for) shrinkage will also "prestress" the panel; the magnitude and benefits of this concrete precompression must be determined on a life-cycle basis before the procedure can be economically justified. The life-cycle effects of the wet mortar on the thermal conductivity of the "sandwiched" polyurethane foam must also be determined. Since structural strength of the W-Panels has been established by ICBO, only a few tests of expansive concrete panels will be needed to verify their strength.

CONCLUSION

Based on results shown in Figure 4, use of expansive cement mortar to prevent shrinkage cracking in the W-Panel is a technically viable concept. Embeddable resistance strain gages are more reliable for measuring strain in the W-Panels than a mechanical strain gage used on embedded screw-type reference points.

RECOMMENDATIONS

To reduce life-cycle and energy costs of new concrete structures by up to 30% by using expansive concrete panels with insulation at mid-thickness to produce crack-free sandwich-type walls and roofs, the research program outlined below is recommended.

1. Experimental sandwich wall and roof panels, containing insulation at mid-thickness, should be made with shrinkage-compensating expansive cement concretes to eliminate shrinkage cracking. Optimum amount of expansive cement, optimum curing method, and optimum panel thickness should be determined. Volume changes (potential to crack from shrinkage), strength, thermal conductivity, and density should be determined on experimental wall and roof panels. In addition, the optimum method of placing the mortar (plaster) should be developed (shotcrete, pumping, etc.).

2. Design procedures, including tables and charts, should be developed for energy-efficient expansive concrete wall and roof panels.

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2. "Recommended practice for the use of shrinkage-compensating concrete," Manual of Concrete Practice, Part 1. American Concrete Institute, 1977. (ACI 223-77)

3. International Conference of Building Officials, Research Committee Recommendation Report No. 2440, Jul 1978.

Figure 1. Sections of W-panels.

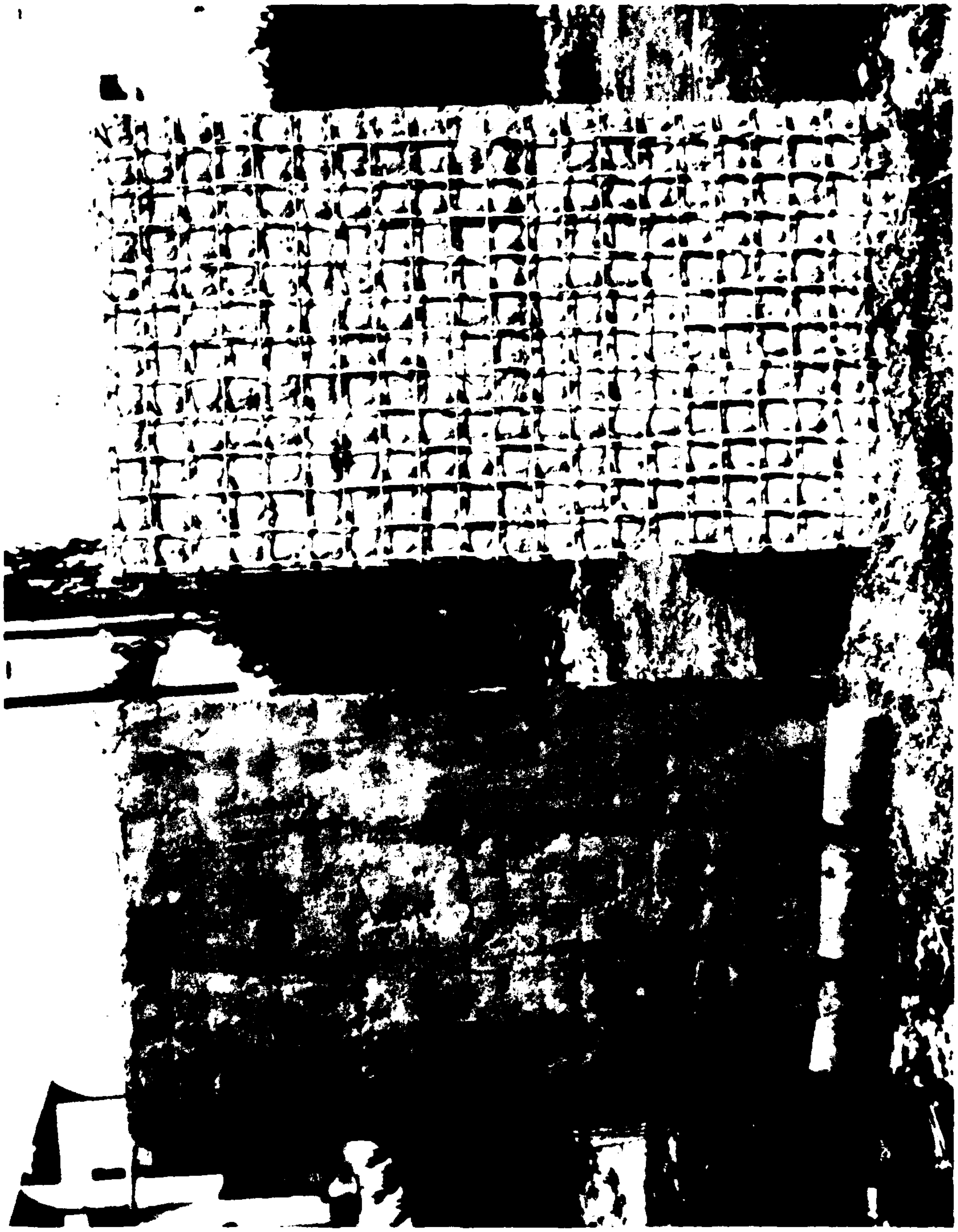

Figure 2. Experimental panels constructed outside.

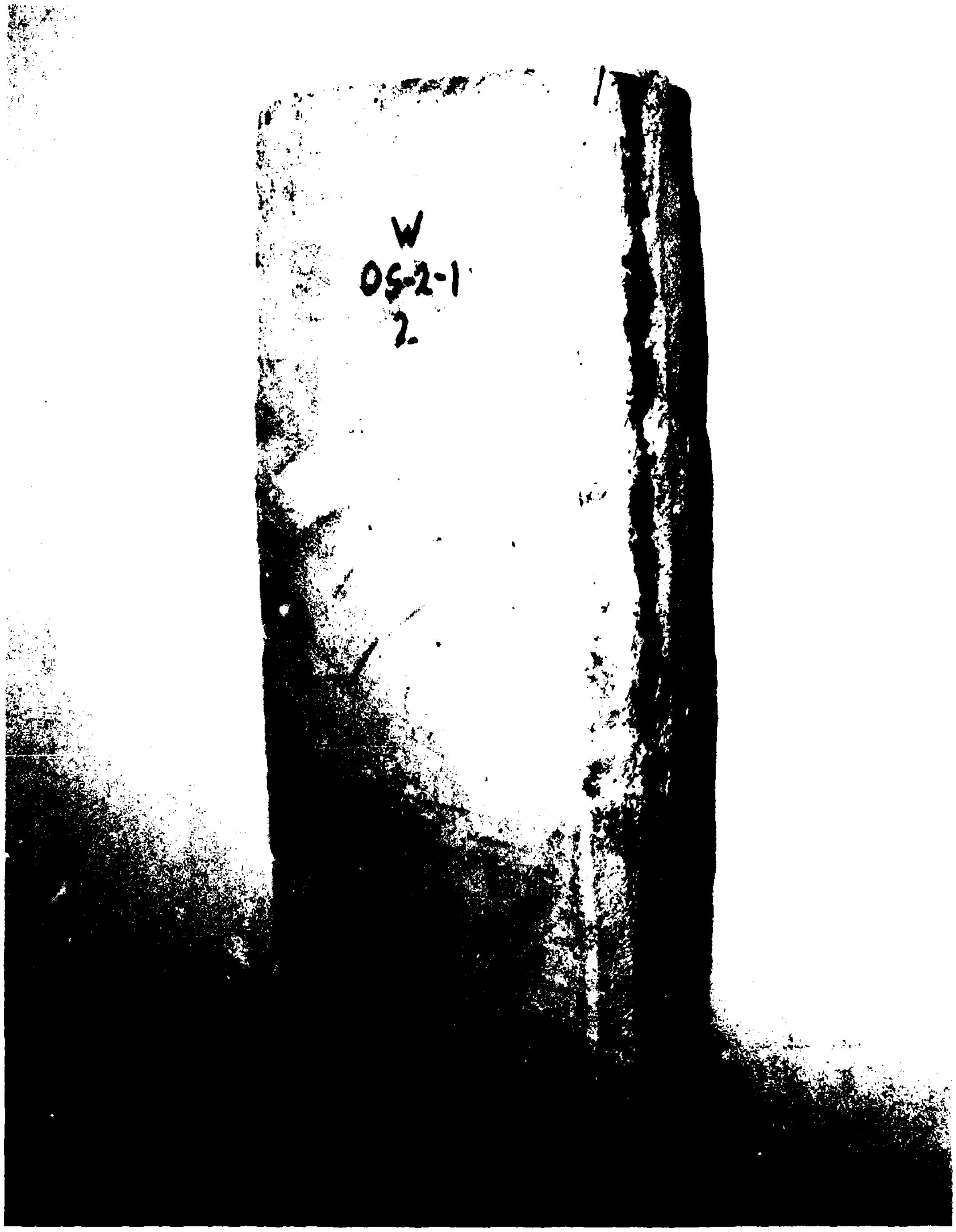

Figure 3. Completed 1 by 2-foot panel, showing screw-type reference points for mechanical strain gage attachment.

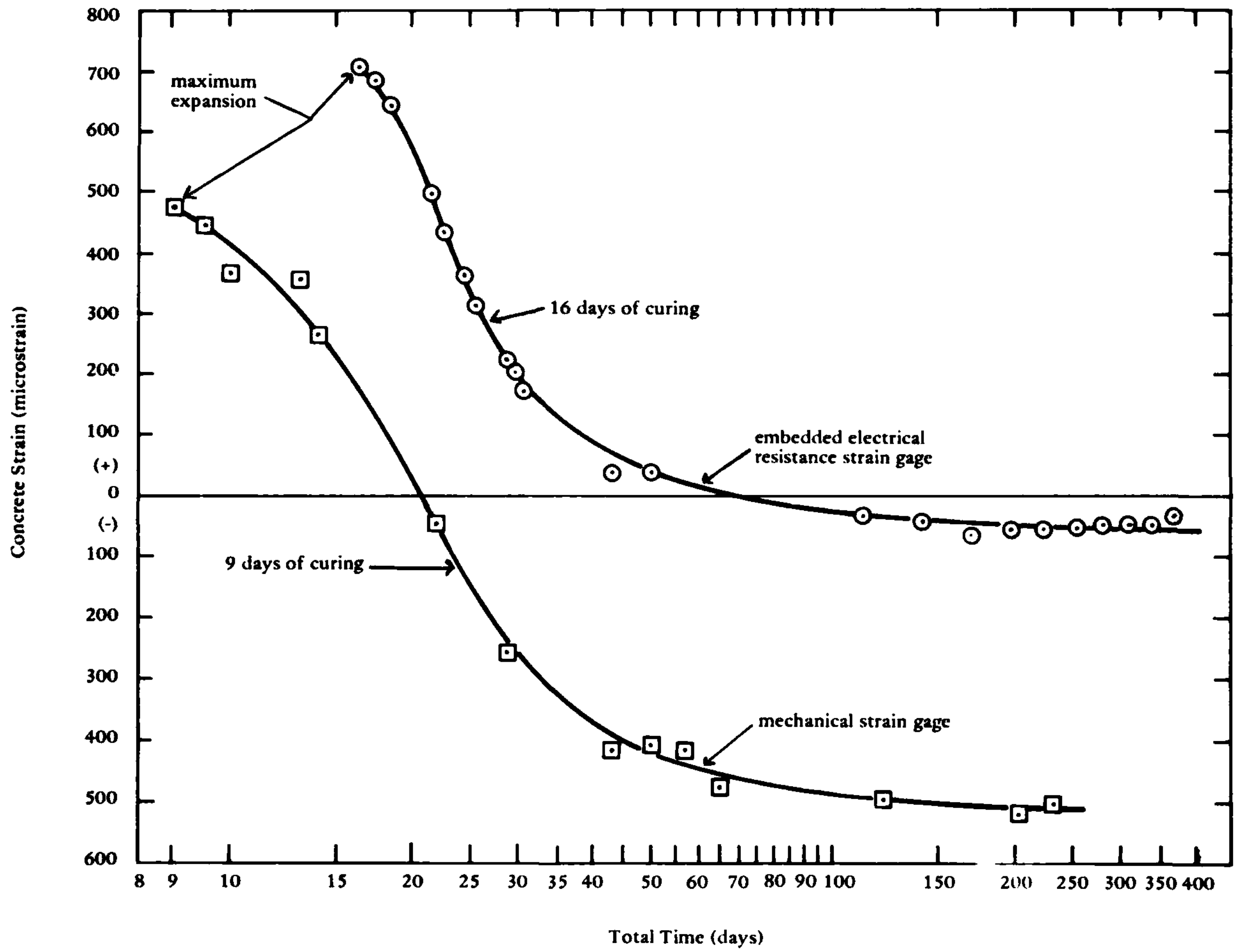

Figure 4. Shrinkage of expansive concrete sandwich wall panels in 50% RH.

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